Hyperon couplings and the electrochemical potential in neutron star matter[1]

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Uncertainty of the hyperon couplings, in particular, that of the Σ^-, in dense matter raises the question of the behavior of the electrochemical potential in neutron star matter, which is crucial to the possible presence of the kaon condensed phase. That hyperons can contribute to the saturation of the electron chemical potential and may preempt thereby the condensation of kaons, depends, at first sight, on the Σ^- since it is the lowest mass baryon of negative charge and can replace a neutron and electron. Extrapolated atomic data suggest that it may feel repulsion at high density, which would mitigate against its appearance in dense matter, although this remains inconclusive. Indeed, it has been suggested that the absence of the Σ^- would mitigate the negative effect that hyperons have on kaon condensation.

However, we show in this paper, that even if the Σ^- is totally absent from dense neutral matter, the Λ hyperon, by itself, or aided by the Ξ^- also causes the electron chemical potential to saturate and then decrease with increasing density. The Λ is known to experience an attractive potential in normal nuclear matter as does the Ξ^-. The Λ can replace neutrons at the top of their Fermi sea with a reduction in the high value of the 3-component of the isospin of neutron star matter, thus reducing the asymmetry energy, and with no increase in electron and proton population with increase of density.

It is apparent from Fig. 1 that the hyperons limit the growth of the electrochemical potential at a density of 2.5 to 3 times nuclear density, and bring about its monotonic decrease at higher density from a maximum value of about 200 MeV, which is far below the vacuum mass of the K^- of 494 MeV. This renders kaon condensation problematic, and further progress on this question will require very accurate evaluation of the behavior of the K^- mass as a function of density, as well as continuing experimental work on hyperon interactions.

The maximum possible mass of neutron stars appears to be ~ 1.5 to $1.7 M_\odot$ independent of the uncertainties, the limit being imposed by any one of hyperonization, deconfinement or kaon condensation. Interestingly, such a limit is barely higher than the Chandrasekhar limit on the iron core mass of presupernova stars. This leaves a very small mass-window for the existence of neutron stars, the occurrence of supernova, and therefore for a universe containing heavy elements and at least one planet with life.

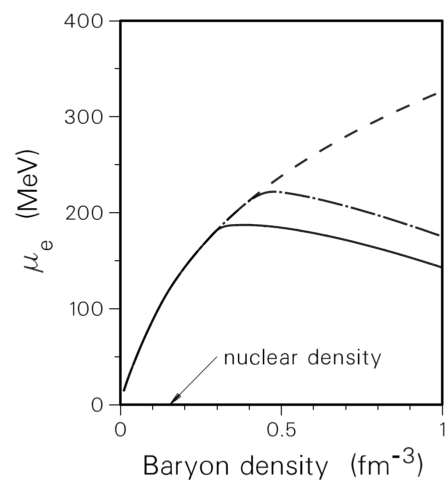

Figure 1: Electrochemical potential in neutron star matter as a function of density. Three cases are compared: (1) only nucleons and leptons are present (dashed line), (2) nucleons, hyperons and leptons are present (solid line), (3) nucleons, leptons and hyperons except the Σ^- are present (dash-dot line).

[1] N. K. Glendenning, Phys. Rev. C **64** (2001) 025801.